GEOPHYSICAL RESEARCH LETTERS, VOL. 8, NO. 5, PAGES 469-472, MAY 1981

THE APPLICATION OF GEOCHEMICAL METHODS IN EARTHQUAKE PREDICTION IN CHINA

Jiang Fong-liang and Li Gui-ru

Institute of Geology, State Seismological Bureau, Beijing, China

and

W. K. Kellogg Radiation Laboratory, Caltech, Pasadena, California 91125

Abstract. Several geochemical anomalies were observed before the Haichen, Longling, Tangshan, and Songpan earthquakes and their strong aftershocks. They included changes in groundwater radon levels; chemical composition of the groundwater (concentration of Ca^{++}, Mg^{++}, Cl^-, $SO_4^=$, and HCO_3^- ions); conductivity; and dissolved gases such as H_2, CO_2, etc. In addition, anomalous changes in water color and quality were observed before these large earthquakes. Before some events gases escaped from the surface, and there were reports of "ground odors" being smelled by local residents. The large amount of radon data can be grouped into long-term and short-term anomalies. The long-term anomalies have a radon emission build up time of from a few months to more than a year. The short-term anomalies have durations from a few hours or less to a few months.

Introduction

Following the destructive Singtai earthquake (M = 7.2) in 1966, a large scale earthquake prediction program was developed in China. Now there are several hundred radon monitoring stations, some of which are automated. At many stations chemical analyses of groundwater are carried out by conventional methods. In addition, at some stations dissolved gases in groundwater are measured by chromatographic techniques. During 1975-77 some of these stations appeared to be sensitive to several large earthquakes, and to some extent geochemical methods played an important role in predicting the Haichen earthquake (February 4, 1975; M = 7.3), the Longling earthquake (May 29, 1976; M = 7.4), and the Songpan earthquake (August 16, 1976; M = 7.2). During this period a large amount of geochemical data was accumulated. This paper is intended to present a sampling of some of the more interesting results that were recorded during this period. A more detailed report is available elsewhere [Jiang and Li, 1980].

Groundwater Radon Anomalies

Groundwater radon anomalies can be grouped into long-term anomalies and short-term anomalies. The long-term anomalies have a radon emission build-up time of from a few months to more than a year. In most cases these are characterized by an increasing trend in radon level before large earthquakes, but decreases also are seen at some stations (Figure 1). The amplitudes of these radon anomalies range from 10% to 30%. (Generally, when long-term averages and standard deviations for geochemical data sets are available, the data are considered anomalous if they depart from the long-term average by substantially more than one standard deviation. However, there is no rigid rule for considering a particular data set anomalous, and overall patterns of change in several types of measurements may be considered as important as a large change in a single parameter.)

Short-term, spike-like radon anomalies appear to be more important for predicting impending earthquakes. The amplitude of these radon spikes generally ranges from 35% to 140%. Some of the better observations were obtained before the Haichen and Songpan earthquakes; and, based on these data, predictions were made by local stations. Typical data are shown in Figure 2. In some cases spike-like anomalies have followed the reversal of long-term anomalies in the same region. Figure 3 shows a typical spike-like radon anomaly observed at Tanghe Sanatorium before the M = 7.3 Haichen earthquake of 1975. This station is located at the intersection of two active faults trending NE and NW respectively, and was 70 km northeast of the epicenter. At this station hot water samples usually were taken once per day; however, starting on 31 January 1975 when there was a rapid increase in the radon level above the ambient variations, sampling was carried out more frequently. Because a strong earthquake appeared imminent, the water was monitored for radon every thirty minutes. Thus it was possible to observe a major radon spike which began only one half hour before the Haichen earthquake.

Soil gas radon anomalies have been observed only at Yanbien station which is located in Jilin province in northeastern China. Beginning about December 25, 1974 soil gas radon content began increasing from 4.5 emans to 6 emans (a 33.7% change) then decreased slightly. A few days later a spike-like soil gas radon anomaly was recorded before the Haichen earthquake.

Anomalies in Water Chemistry

The analyses of the chemical composition of groundwater from hot and cold springs and from boreholes began, for the most part, only after the Tangshan earthquake. Some anomalous changes were observed in the ionic composition of groundwater before and coincident with the major aftershock of the Tangshan earthquake (Ninghe earthquake; M_s = 6.9, 1976). These changes in the levels of Ca^{++}, Mg^{++}, Cl^-, and $SO_4^=$ are shown in Figure 4. Interesting anomalous changes in the F^- content of hot spring water and of water in boreholes also have been seen in apparent response to large tectonic strain events.

Paper number 1L0589.
0094-8276/81/001L-0589$01.00

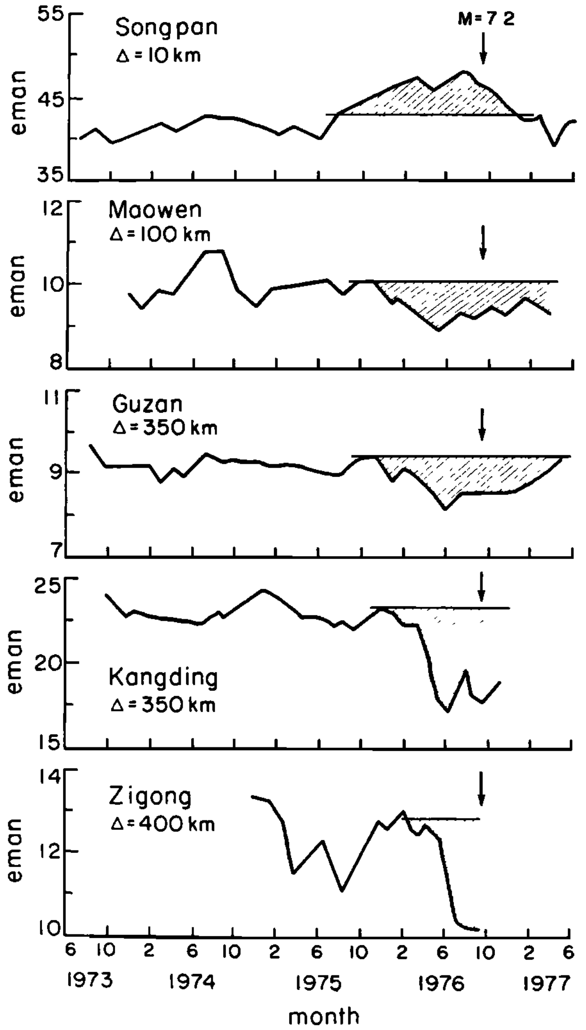

Fig. 1. Ground water radon data from five locations before the M = 7.2 Songpan earthquake. (Data courtesy of the Sichuan Seismological Bureau.)

Anomalous changes in the hardness and conductivity of water occasionally have been observed before large earthquakes (Figure 5).

Anomalies in Dissolved Gases

Anomalies also have been observed in dissolved gases other than radon. The association between anomalies in total volume of dissolved gases, H_2, and CO_2 and large earthquakes is illustrated by the data shown in Figures 6 and 7. Synchronous anomalous changes in CO_2 content and total volume of dissolved gases were observed at the Jin-er station in Tienjin before the Tangshan earthquake (Figure 6).

The H_2 content of water from the Guanghua borehole has shown sensitivity to tectonic events. H_2 is the lightest and most mobile gas, and it is also related to the igneous rocks underlying this station. The borehole at Guanghua is 1000 m deep and is located in the geothermal area of the Beijing depression in the eastern suburbs of Beijing. The borehole is drilled through Cenozoic basalt of several hundred meters thickness which overlies the late Precambrian (Sinian) karstified and fractured limestone which is rich in hot water of the Cl-Na type. The Beijing depression is cut by a series of deep, northeast striking faults from which the hot water issues. Beginning about November 6, 1976, nine days before the 6.9 M Ninghe earthquake, the H_2 content of the water in the Guanghua rapidly increased from 40 to 408 in relative units, showing a spike-like anomaly 10 times the ambient level (Figure 7). This anomaly continued for several months, and only subsided after an M = 6.0 aftershock of this earthquake.

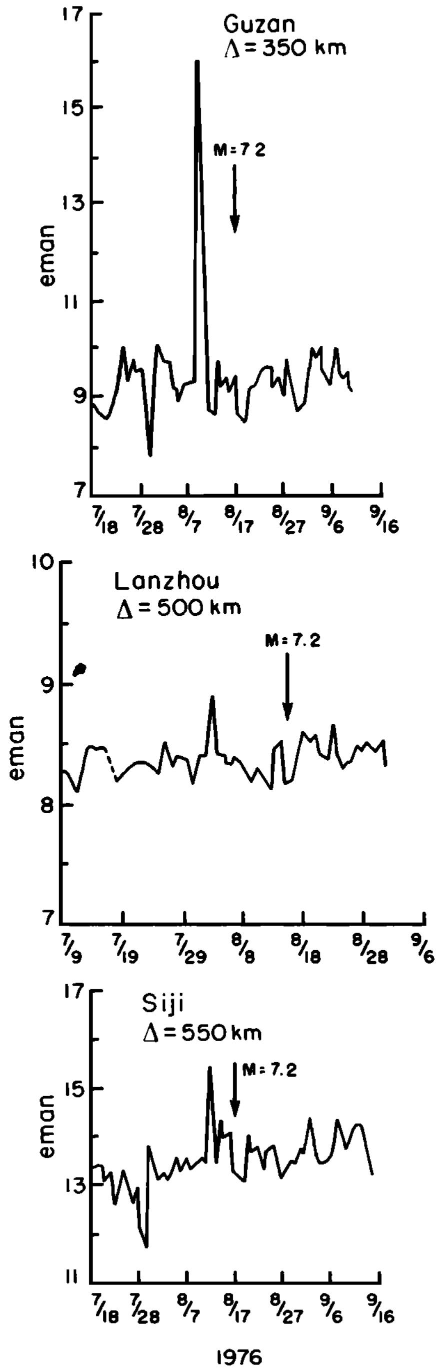

Fig. 2. Spike-like ground water radon anomalies observed at three locations before the Songpan earthquake. (Data courtesy of the Sichuan Seismological Bureau.)

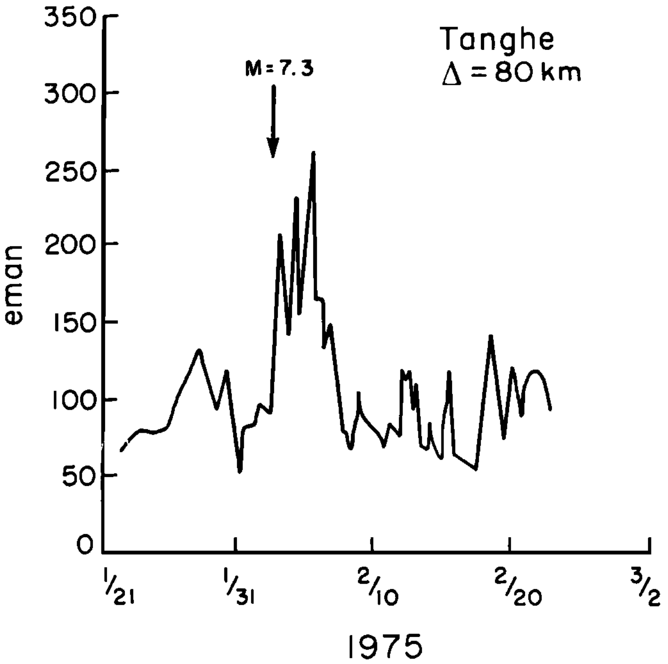

Fig. 3. Spike-like radon anomaly observed at Tanghe before and after the M = 7.3 Haichen earthquake. (Data courtesy of the Liaoning Seismological Bureau.)

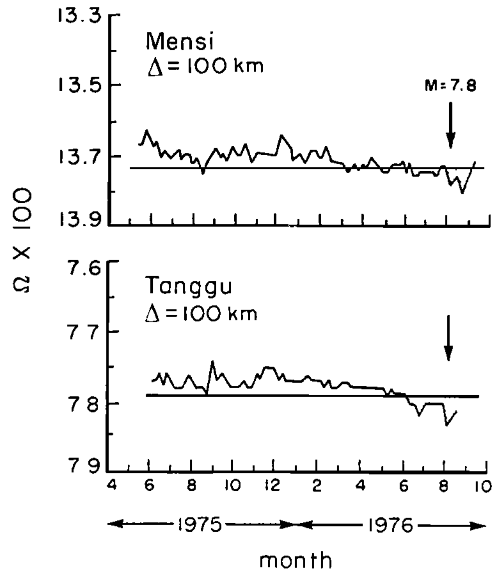

Fig. 5. Anomalous changes in the resistivity of water observed at two locations in Tienjin before the Tangshan earthquake of 1976. (Data courtesy of the Tienjin Seismological Bureau.)

Other Anomalous Phenomena

From field investigations before and after large earthquakes, we have found a number of macroscopic geochemical phenomena including short-term changes in water color and quality, as well as burning gas, the escape of subsurface gas, and fog on the surface of the ground. In addition, anomalous changes in water temperature and ground temperature were recorded before two events. Many of these data were obtained with the help of local volunteers.

It was found that at the southwest end of the northeast trending Longmenshan fault in Qunlai, Sichuan province, well water would turn blue or black when used to make tea in April 1976, a few months before the Songpan earthquake. According to local residents, not even bean curd could be made with this water (implying a large increase in salinity), something which had never happened in the past.

A possible reason for these anomalies is that the Sichuan basin is rich in natural gas, hot brine, and chemical deposits such as anhydrite and gypsum. The supposition is that during the Songpan tectonic strain event, rock fracturing and cracking might have occurred followed by mixing between upper and lower aquifers having different chemical composition. This mixing may have changed the color and quality of well water, and may have released high temperature and high pressure gas from the deeper parts of the basin which rose along the fractures.

A very unusual event was noted before the Tangshan earthquake. A "fountain" of gas was emitted from the Wan Quan Zhuang well. This well is 7 m deep and is located on an active fault about 160 km to the east of the epicenter of the Tangshan earthquake. About a day before the main

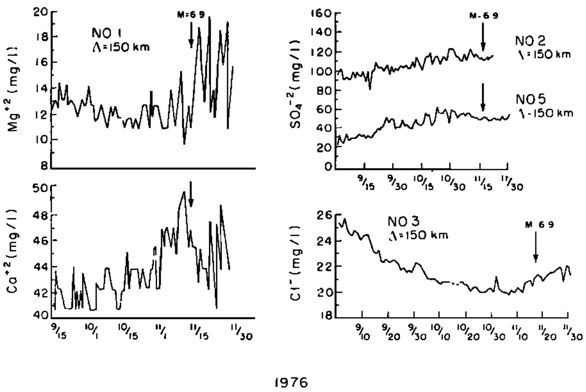

Fig. 4. Anomalous changes in ionic composition of ground water observed in the Beijing area before the Tangshan earthquake and its aftershocks.

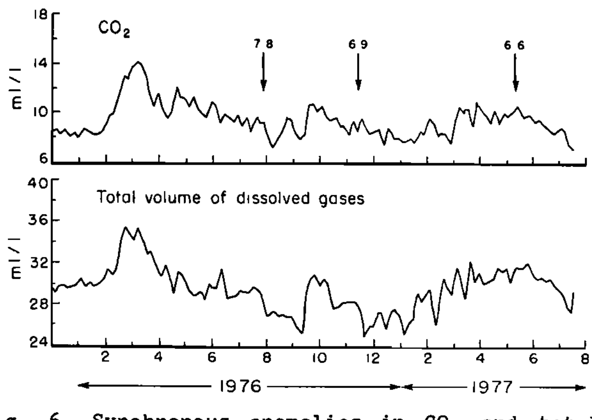

Fig. 6. Synchronous anomalies in CO_2 and total volume of dissolved gases observed at Jin-er in the Tienjin area prior to the Tangshan earthquake and its aftershocks. (Data courtesy of the Tienjin Seismological Bureau.)

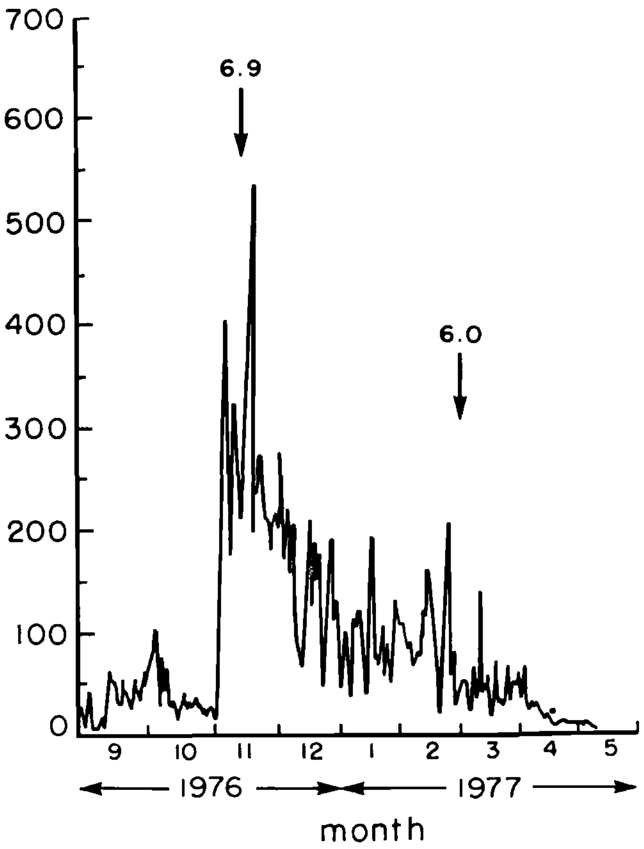

Fig. 7. Spike-like anomaly in H_2 content recorded in water from the Guanghua hot water borehole (1000 m deep) in Beijing prior to the M = 6.9 Ninghe earthquake of 1976.

shock, a fountain-like stream of gases issued from the well making a loud noise which could be heard some 200 m from the well. The stream of gases ceased five hours before the Tangshan earthquake occurred. On 28 July at 0900 local time, the "fountain" began again. At this time instrumental measurements were carried out. The gas stream was found to be 2.5 m high, and the flow velocity was 38 m/sec. An analysis of the gas showed that the concentration of CO_2 reached 12.85% (by volume).

So-called "ground odors" were detected before almost all of the large earthquakes which occurred during the last decade. For instance, early in January 1975, people from the epicentral area of the Haichen earthquake reported noticing strange odors. These resembled the odors of sulphur, H_2S, hot tar or phosphorous. It was reported that someone from Youyan (40 km southeast of Haichen) lost consciousness from inhaling these vapors.

Besides all of the previously mentioned phenomena, a close association has been noted between water and ground temperatures and strain events. Coincident with the radon anomalies prior to the Tangshan earthquake, the water temperature at the Changli geothermal well started to decrease on July 20, 1976. Then from July 24 to July 26 there was a spike-like increase in water temperature from 45°C to 50°C. At the maximum in this spike, the earthquake occurred. During the same period, the ground temperature measured at 0.8 m beneath the surface increased. The largest amplitude increase (1.6°C) was observed at the very epicenter of the earthquake.

Concluding Remarks

Generalizing from the above-mentioned anomalies, from tests with explosives, and from experimental studies of rock rupture under stress loading [Jiang and Li, 1981]; we suggest that the precursor field appears to be governed by the stress field which gives rise to the subsequent earthquake. Thus it is reasonable to expect that geochemical anomalies may have a close association with regional seismic activity on one hand, but on the other hand these anomalies may vary with different focal mechanisms of the earthquakes, tectonic structure, geological history, geochemical environment, and hydrogeological conditions of a given area. From the available data, several tentative conclusions have been drawn by Chinese scientists:

1) There is a close relationship between the onset of radon anomalies, their amplitudes, and their distance from the impending earthquake. Generally speaking, the nearer the radon monitoring site to the epicenter, the earlier the anomalies begin, and the larger the amplitude observed.

2) Long-term groundwater radon anomalies may be associated with seismic activity over a wide area.

3) In response to a tectonic strain event, the sensitivity of a given site may depend strongly on its geology and tectonics [Teng, 1980].

4) A close association exists between geochemical anomalies and hydrogeological conditions in the vicinity of the stations. Stations located on alluvial fans are mostly controlled by meteorological changes in the area, and there is no clear association between geochemical anomalies and earthquakes. In contrast, those stations which are located in basement rocks often show obvious responses to large earthquakes.

Acknowledgments. The authors wish to thank Professor T. A. Tombrello and the staff of the W. K. Kellogg Radiation Laboratory for providing facilities during our visit to the United States. We thank Dr. M. H. Shapiro for his comments and advice concerning this paper, and we thank Ms. H. Marr for drawing several of the figures.

References

Jiang, F. and G. Li, The application of geochemical methods in earthquake prediction in China, W. K. Kellogg Radiation Lab. preprint LiAP-37, Caltech, Pasadena, CA. 1980.

Jiang, F. and G. Li, Experimental studies of the mechanisms of seismo- geochemical precursors, Geophys. Res. Lett., this issue.

Teng, T., Some recent studies on groundwater radon content as an earthquake precursor, J. Geophys. Res., 85, 3089, 1980.

(Received February 12, 1981;
accepted March 31, 1981.)